Investigation of Single Mode Square Lattice Photonic Crystal Fiber with Ultraflattened Dispersion

Lisha Agrawal, Himanshu Joshi, Khushbu Sharma

***Abstract*— This paper presents a new single mode photonic crystal fiber based on square lattice structure with ultraflattened dispersion and also the two different air-hole diameters in cladding region is proposed. In this article, the dispersion is investigated using a proficient compact two dimensional finite-difference time-domain (2-D FDTD) method and the anisotropic perfectly matched layer (PML) for the boundary treatment. To examine the single properties of PCF like dispersion and other polarizing properties the outcome of variation in wafer dimension of a constant lattice size is analyzed. The elementary characteristics of single mode photonic crystal fibers (SMPCFs) such as chromatic dispersion are numerically investigated and Normalized frequency parameter parameter is also being estimated in this paper. We find that the proposed photonic crystal fibers demonstrate properties of ultraflattened nearly zero dispersion of 0±0.6ps/(km·nm) in wavelength range of 1.3 to 1.6 µm through numerical simulation and optimizing the geometrical parameters.**

***Index Terms*— Chromatic Dispersion, Photonic Crystal Fiber, Single Mode Fiber, Square Lattice, V parameter.**

I. INTRODUCTION

In recent years, there has been major interest in Photonic crystal fibers having several advantages such as endlessly single-mode [1] [2] [6] at all wavelength, tailorable effective modal areas, anomalous dispersion [5] at visible and near infrared band and highly birefringent [5] [8] [15] effect [1]. PCF is generally considered by a series of air holes that runs throughout the length of the fiber [4] and also it is based on total internal reflection, has been popular for a long time [16]. Light is guided in PCFs with two types of effects: the first one direct light by total internal reflection between a solid core and a cladding region with multiple air-holes and the second one uses a absolutely periodic structure displaying a photonic band gap [2] effect at the operating wavelength to guide light in a low index core region, which is also called photonic band gap fiber [4] [6]. To attain ultraflattened dispersion in PCFs, several fascinating designs have been proposed [1].

The design of PCFs is very flexible. Various parameters are involved to influence: lattice pitch, air hole shape and diameter, refractive index of the glass, and type of lattice. Freedom of design allows one to attain endlessly single mode fibers, which are single mode in all optical range and a cut-off wavelength does not exist [12]. The distance between the holes is known as lattice pitch which is denoted by Λ and the diameter of the air holes is specified by d and is expressed as the structural parameter of the PCF and the ratio d/Λ is called air filling fraction [4].

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In PCFs [12] [17], control of dispersion is very important problem for realistic applications [1] [3] [5-11] in both the linear and the nonlinear regimes of optical fiber communications [1] [14] [19]. Various stimulating designs have been proposed to attain ultraflattened dispersion in PCFs [1]. In all cases, almost-flattened fiber-dispersion behavior becomes a critical issue [19]. Due to the effect of the variation in the wafer dimensions, the dispersion shows a randomly behaviour [16]. In order to obtain the ultra-flattened dispersion properties, various designs have been proposed for the PCF [14]. The property of Single mode in PCF is very useful for communication system application [18]. In view of the fact that most of the earlier designs are all based on triangular PCFs, and the depiction on ultraflattened dispersion properties of square-lattice PCFs is very few. Consequently, it is very important to explore ultraflattened dispersion in square-lattice PCFs [1].

The outline of this paper is the following: in the next section, we describe our theoretical part of PCF. In the section III, we have described the structure of our proposed design of square lattice PCF to achieve the desirable characteristics. After that simulation results have been discussed of our proposed structure.

II. THEORITICAL ANALYSIS

In this paper, we suggest a new class of single mode square-lattice photonic crystal fiber with five rings air-holes having inner and outer diameter and of constant pitch whose structure is analogous to that in Ref [1]. In order to avoid the general complications of the fabrication process only two different air-hole diameters are used. A compact two-dimensional (2-D) finite difference frequency domain approach described in Ref [13] with anisotropic perfectly matched layers (PML) absorbing boundary conditions is used. The considered results show that our proposed PCF can concurrently realize ultra-flattened dispersion and Normalized Frequency Parameter i.e., V Parameter in a wide wavelength range [1].

A. Chromatic Dispersion

Chromatic Dispersion is the observable fact that in a transparent medium the group velocity of light depends on the optical frequency or wavelength. This can be obtained by the second derivative of the real part of the refractive effective index. The whole dispersion is called chromatic dispersion and it is the sum of material dispersion and waveguide dispersion [5]

$$D_{Chromatic} = D_{Material} + D_{Waveguide} \tag{1}$$

The chromatic dispersion D of PCFs can be easily considered from the effective index neff= B/k0 in opposition to the wave length using [1]

$$D_{Chromatic} = -\frac{\lambda}{c}\frac{d^2 Re(n_{eff})}{d\lambda^2} \qquad ps/nm/km \tag{2}$$

Where λ is the wavelength, c is the velocity of light in a vacuum and Re stands for the real part correspondingly. Since the hole diameter to pitch ratio is very small and the hole pitch is large, the dispersion curve is close to the material dispersion of pure silica. When the air-hole diameter is improved, the control of waveguide dispersion becomes stronger. Hence we can see that if there is correct change in geometrical parameters such as hole pitch and hole diameter it is probable to shift the zero dispersion wavelength to visible to near-infrared (IR) regions [6].

B. Normalized frequency of PCFs

It can be defined as an effective V-parameter which or a normalized frequency parameter, which establishes the number of modes of a photonic crystal fiber and hence this can be expressed as [5]

$$V_{eff} = 2\pi\frac{\Lambda}{\lambda}\sqrt{n_{core}^2 - n_{eff}^2} \tag{3}$$

Which must be less than 2.405 for the single mode fiber, where Λ is the hole pitch, λ is the wavelength in vacuum, the n_{core} is the refractive index of the core, which is silica and n_{eff} is the effective refractive index [5].

III. DESIGN OF SQUARE LATTICE PCF

According to their lattice structures, the photonic crystal fibers may be categorized into two different types; triangular lattice and square lattice. In this paper, the proposed PCFs are of the square-lattice type [10]. The schematic diagram of proposed square-lattice PCF with five rings of holes is made of pure silica surrounding with circular air-holes in the fiber cladding is shown in Fig.1

The structure has optimized air hole diameter d, d1 and pitch Λ where and d1 is the air hole diameter for the inner three rings, d is the air-hole diameter for the outer two rings. The structure has one missing air-hole in first ring. The spacing between air-holes on same ring of the square structure is same as the pitch Λ.

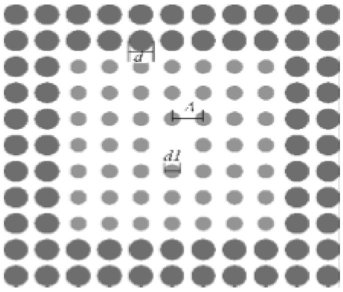

Fig. 1 The Schematic diagram for Proposed Square Lattice PCF with five rings of holes Design

In the designed Square lattice photonic crystal fiber, the air-holes of the first, second and third rings are comparatively small to that of fourth and fifth rings by which this increase in diameter of last two rings origins high negative dispersion peak. The diameter of air-holes of inner three rings is very smaller, which causes changes in the slope of the dispersion. The schematic cross section of proposed square lattice PCF is shown in fig.2.

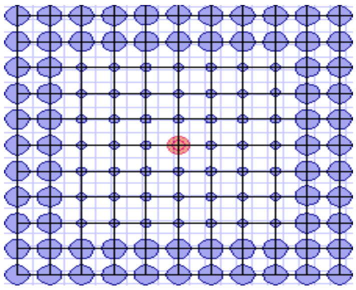

Fig. 2 The Cross Section of Proposed Square Lattice PCF Design-3

Firstly, by using the numerical scheme obtained above, the dispersion as a function of wavelength for various different d1 is intended, and the material dispersion given by Sellmeier's formula is directly taken into account in the calculations [1]. Additionally polarization current density is being introduced in order to formulate Sellmeier formula and hence material dispersion of fused silica can also be coursed. On the other hand, for frequency-dependent material, which the Sellmeier formula may not present accurate assessment of the material permittivity, their formulation is no longer adequate [13].

IV. SIMULATION RESULTS AND ANALYSIS

In this proposed single mode square lattice PCF structure, effect of varying the dimensions of wafer of the structure is being presented, design-1 to design-4 show the effect of varying the dimensions of the wafer structure for dispersion loss and V parameter determination while keeping the diameter of outer two rings (d) and inner three rings (d1) as constant and are equal to 0.7777µm and 0.31815µm respectively, and the spacing between the adjacent air holes or pitch (Λ) as 2.06µm. Consequently, in these designs we make change in the dimensions of the wafer of the proposed structure.

For design-1, the wafer dimensions of the structure is taken as 22.59µm, for designs 2, 3 and 4, the wafer dimensions are taken as 22.55µm, 22.5µm and 22.6µm, respectively. In order to see the difference between these designs, we plot a comparison graph of ultraflattened dispersion of square-lattice PCF between these four designs.

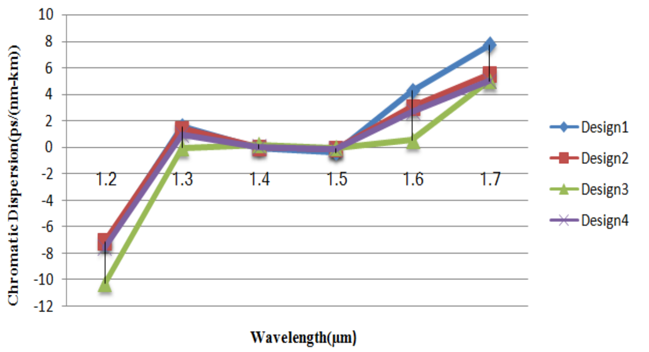

Fig.3 Total Dispersion for Design-1 to Design-4

In Fig.3, the total dispersion graph is shown for design1 to design-4. It shows that as we increase the dimensions of the wafer for dispersion, curve shifts toward zero dispersion line. In Design-3 we see that dispersion value crosses the zero axis three times, first goes from negative to positive, then from positive to negative and then again from negative positive in the wavelength range 1.3µm to 1.6µm .

It can also be observed that for Design-4, when the wafer dimensions are 22.5, shows almost flat dispersion at the 1.3µm to 1.5µm wavelength range but there is no value at 1.6 µm as compared to Design-3.

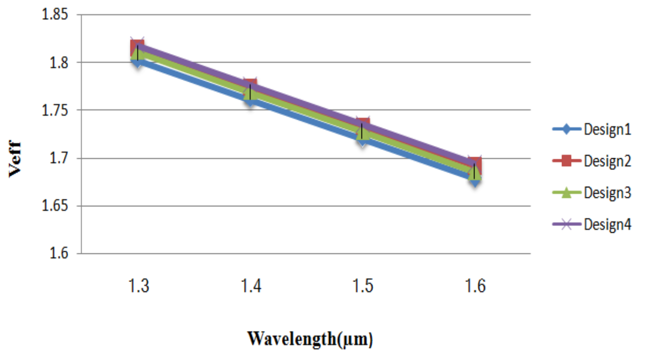

Fig.4 V-parameter for Design-1 to 4

Here, in Fig.4, the effective V-parameter representation of all proposed Design-1 to Design-4 is described with the help of graph. We can see from this figure, the effective V parameter decreases as wavelength elevate for all the designs and the value of V parameter is less than 2.405 as required in single mode fiber.

From above study, it is found that Design-3 shows a low chromatic dispersion and is found that the dispersion line crosses the zero axis which is almost flat. In addition, it is also observed, that the proposed design show a low and flattened dispersion profile on different wavelength channels, which is the application for wide wavelength range.

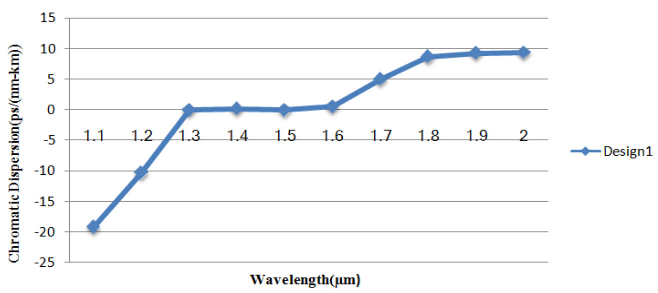

Fig.5 Chromatic dispersion dependence with wavelength for Design-3

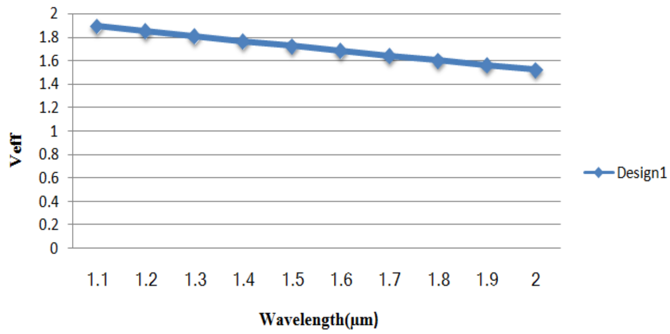

Fig.6 V Parameter dependence with wavelength for Design-3

Figure-6 shows the dependence of V Parameter with wavelength. It can be observed that in Design-3, V Parameter decreases as the wavelength increases for wide band range. In our observation value of V Parameter is very low as required for a single mode fiber which is $V \leq 2.405$. So, this value is low for this range of single mode fiber and does not affect the transmission. A low value of V Parameter required for polarization maintaining fiber or for successful transmission of information at wide wavelength range.

V. CONCLUSION

Hence, we have designed and explored the optical properties of a meticulous type of PCF with square lattice of air holes. The dispersion characteristics and the fiber V-parameter have been numerically investigated using finite difference time domain method. From this proposed design, it is also observed that design-3 provides a low-flattened dispersion and low V Parameter as compared to design-4 in the wide spectral range as per in the desired wavelength range of V Parameter for single mode fiber . The results obtained in this work would be useful in designing the PCFs with especially large numerical aperture, multi-moded and square field distribution. The fiber have anomalous dispersion over a wide range of wavelength.

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